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13. ABSTRACT *(Maximum 200*

This study determined the effectiveness of microclimate cooling (MCC) as a countermeasure to heat stress in women versus men. Subjects alternated 10 min rest with 20 min moderate exercise for 120 min in a hot environment (35°C/65% relative humidity) for four trials: No Cooling (NC), Air Cooling (AC), Ice Vest Cooling (IVC), and Water Cooling (WC). Heart rate (HR), core temperature (T_{re}), and sweat rate (SR) were compared across conditions. Results indicate MCC minimized heat strain in women and men. Final HR (bpm) between women and men was significantly different with AC (142 ± 20 vs. 113 ± 17), NC (169 ± 7 vs. 142 ± 26), IVC (151 ± 17 vs. 121 ± 21), and WC (125 ± 10 vs. 104 ± 12). A significant gender difference was found in final T_{re} (°C) during AC (38.3 ± 0.6 vs. 37.5 ± 0.5) only. T_{re} was also higher for women than for men in the other conditions, however these differences were not significant. SR showed a trend across conditions: NC > AC > IVC > WC, with women tending to have lower SR than men. The results indicate, generally, that cardiovascular compromise was greater in women than men in all conditions.

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Principal Investigator's Signature   Date

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IV. TABLE OF CONTENTS

V. INTRODUCTION

Microclimate cooling (MCC) has been used when military tasks require work in noxious environments or in protective garments (e.g., chemical, biological, radiological ensembles [CBRs] and firefighting ensembles). The effectiveness of MCC to minimize heat strain in women has not been addressed. Current models of thermoregulation suggest that established gender differences in three areas may influence the effectiveness of MCC in females when compared with males. These areas are physical fitness, anthropometry, and sweat rate.

Physical fitness has been shown to differ between male and female military personnel. Physical strength in female recruits after basic training was 60% of upper-body and 67% of lower-body strength of male recruits (1). Military females have 75% of the aerobic ability (2) and 30% longer 1.5-mile run times (3) than military males. Considering that some microclimate cooling systems (MCSs) weigh up to 16 pounds, use of this equipment requires women to lift and carry a greater percentage of maximal capacity than men. Additionally, the metabolic cost associated with wearing an MCS requires women to perform work at a higher percent of their aerobic ability. Thus, when using an MCS, onset of muscular fatigue may be hastened in females and could produce a greater impairment of females to perform submaximal exercise. Therefore, the weight of an MCSs may be problematic and could offset the cooling advantage in females.

Anthropometric differences between genders have long been noted. Anthropometric studies involving 214 women and 602 men found that Navy women were, on the average, 5 inches shorter and 50 pounds lighter

than Navy men (4,5). The smaller body size of women compared with men may create a logistical problem for fitting of a cooling device. In addition, due to sensitive breast tissue, placement of a cooling apparatus on the thorax may be problematic in women. This is especially relevant for the ice vest currently used aboard ship. Another gender difference in anthropometry, distribution of muscle mass, may influence decisions in regard to placement of an MCS on the body. In a military population, women have 30% less muscle mass (54 pounds) than men (6), with relatively more mass distributed in the legs than the in arms (7). Because heat extraction is enhanced in areas overlying active muscle tissue (8), location of muscle mass impacts decisions for regional placement of the MCS.

Sweat rate (SR) has been found to be greater in men than in women (10-12). SR is an important thermoregulatory response to physical performance in the heat and can be a determining factor for the following: heat illness, fluid consumption requirements; and type of cooling system employed. A greater SR confers a larger capacity for heat loss via evaporation. Since an air-based MCS functions by increasing evaporative heat loss, air cooling may be less effective in females than males.

Effective microclimate cooling (MCC) is essential for prevention of heat strain, and ideally, maintenance of thermal balance in hot (and noxious) environments. Currently, effectiveness of MCC for females has not been determined. Due to gender differences in thermoregulation and anthropometry, some cooling systems may confer greater cooling in women than in men.

The purpose of this study was to determine the effectiveness of microclimate cooling as a countermeasure to heat stress for females and to determine if there was a gender difference in the efficacy of three different cooling systems (i.e., a water-based system, an air-based system, and an ice vest-based system). Cooling system efficacy was assessed by examining indices of heat strain (i.e., heart rate, core temperature, and sweat rate).

VI. BODY

A. METHODS

<u>Subjects</u>:

Sixteen military personnel, after a medical review and written consent were given, served as subjects for this test. The physical characteristics of the subjects are shown in Table 1.

Table 1 - Physical Characteristics of the Subjects

Variable	Total (N=16)	Males (N=12)	Females (N=4)
Age (years)	24.6 ± 5.3	22.9 ± 4.1	29.5 ± 6.0
Height (cm)	171.4 ± 5.7	171.6 ± 6.5	170.7 ± 2.4
Weight (kg)	69.8 ± 8.3	71.9 ± 7.9	63.7 ± 6.9
$\dot{V}_{O_2}$max (L/min)	3.75 ± 0.76	3.87 ± 0.73	3.28 ± 0.82
Body Fat (%)		15.1 ± 4.4	24.8 ± 6.6

<u>Experimental Design</u>:

Each volunteer participated in one preliminary visit and four 120-min experimental trials where moderate intermittent exercise was required in a hot environment (35°C and 65% relative humidity). To minimize treatment interaction, test sessions were separated by at least 2 days. The participants completed the following four experimental conditions in a counterbalanced fashion:

1. No cooling (NC) -- No MCS was worn under the CBR ensemble.

2. Air-based Cooling (AC) -- An air-based MCS was worn under the CBR ensemble. The torso air cooling system consisted of a lightweight nylon vest, that had an interior distribution system in the front and back through which air passed. The vest and distribution system had a mass of 0.5 kg. The air was delivered to the vest by a temperature-controlled system designed by Carlson, Inc.

3. Ice-based Cooling (IVC) - Under the CBR ensemble, the volunteer wore a torso cooling vest manufactured by Steele (Kingston, WA). The vest consisted of heavy canvas in which pockets were sewn. Packets of phase change material (cornstarch and water), that were frozen to -20°F, were inserted into the vest pockets. The vest and packets together had a mass of 5 kg.

4. Water-based cooling (WC) - Under the CBR ensemble a water cooling suit was used to remove excess heat (i.e., environmental and metabolic heat) from the volunteer. The suit consisted of a nylon garment embedded with a network of flexible plastic tubing. The tubes were in direct contact with approximately 20% of the body surface area. A total of 157 m of tubes were distributed over six separate body regions: head/neck (11%), arms (18%), upper torso (15%), lower torso (14%), thighs (18%), and lower legs (24%). Water was circulated to the tube suit at 20°C from a temperature-controlled reservoir. The suit and its instrumentation carried by the volunteer had a mass of 8 kg.

Experimental Procedures:

Preliminary Trial

Body composition of each subject was assessed using skinfold measurements. Percent body fat and lean body mass were calculated using regression equations presented by Durnin & Womersely (13).

Maximal oxygen consumption ($\dot{V}O_2$max) was determined using a graded exercise protocol. Each subject exercised to volitional exhaustion, or the test was terminated when the criteria for $\dot{V}O_2$max was achieved (i.e., no increase in heart rate (HR) or oxygen consumption ($\dot{V}O_2$) with an increase in work load). Expired gases were analyzed by open-circuit spirometry (Ametek S-3A/I O_2 analyzer and Ametek CD3A CO_2 analyzer). $\dot{V}O_2$ was measured at 15-s intervals. $\dot{V}O_2$max was determined by taking an average of the three highest consecutive 15-s intervals. During the test, HR was recorded by a monitor that consisted of electrodes on a chest strap which continuously transmitted a signal to a wristwatch receiver (Polar Heart Watch; Stamford, CT). HR data was recorded as a 5-s average. Maximal heart rate (HR_{max}) was determined by taking an average of the three highest consecutive 5-s recordings.

Experimental Trial

Adequate hydration was ensured by the following: (1) instructing the volunteer to avoid heat exposure, alcohol consumption, and strenuous exercise 24 hr prior to each trial; and (2) to drink at least 24 ounces of noncaffeinated fluid 12 hr prior to each trial.

The specific gravity of the volunteer's urine prior to each trial was determined. Euhydration was defined as urine specific gravity of < 1.030.

A change in plasma volume was determined by comparing pre and post values of hematocrit (HCT) using the following formula:

A = 100 ÷ 100 - pre HCT   B = (pre HCT - post Hct) ÷ post HCT

Plasma Volume Change = (A x B) x 100%

Total-body SR was calculated from body mass loss during heat exposure corrected for urine output and fluids consumed. Sweat evaporation was estimated from the difference in body mass while dressed before and after the heat exposure, accounting for urine output and fluid consumption.

Skin temperature (T_{sk}) was measured with thermistors (Yellow Springs Instruments, Inc; Yellow Springs, OH) placed on the left side of the body at the following sites: cheek (ch), scapula (sc), abdomen (ab), forearm (fa), hand (ha), thigh (th), calf (ca), and foot (fo). The mean skin temperature, $\bar{T}_{sk}$, was calculated from the following formula: $(0.07 * T_{ch}) + (0.175 * T_{sc}) + (0.175 * T_{ab}) + (0.14 * T_{fa}) + (0.05 * T_{ha}) + (0.19 * T_{th}) + (0.13 * T_{ca}) + (0.07 * T_{fo})$ (14).

Rectal temperature (T_{re}) was measured via a disposable thermistor probe (Sheridan; Argyle, NY) inserted to a depth of 15 cm beyond the anal sphincter. The rectal and skin thermistors were connected to a digital analog recorder (Science Electronics, Inc; Miamisburg, OH) for continuous visual monitoring and data recording every minute.

Heart rate (HR) was recorded by a monitor as described previously. HR data were recorded as 1-min averages.

The volunteer donned a clothing ensemble after bioinstrumentation was completed. The volunteer wore the following clothing layers: (1) shorts, underwear, and socks; (2) cooling device; (3) coveralls and athletic shoes; and (4) CBR ensemble (Saratoga) in a modified mission oriented protective posture III (MOPP III) configuration (no boots, gloves, or mask).

After dressing, and prior to entering the chamber, baseline measurements of HR, T_{re}, and T_{sk} were recorded for 10 min. During the cooling trials, cooling was provided during this time period. Upon entering the chamber, the volunteer sat for 10 min. After 10 min of seated rest the subject walked on a treadmill set at 3 mph and 2% grade. After 15 min of walking, each volunteer's oxygen consumption ($\dot{V}_{O_2}$) was measured with a Vista System (City, State). $\dot{V}_{O_2}$ was measured at 30-s intervals and reported as an average over two minutes. Iterations of 10 min rest and 20 min exercise continued until one of the following criteria for termination of the experiment was reached: (1) T_{re} of 39.5°C during exercise; (2) T_{re} of 39.2°C during rest; (3) 90% of HR_{max} during exercise for 5 min; (4) 80% of HRmax during rest for 5 min; (5) sweat cessation, nausea, vomiting, retching, syncope, cramps, dizziness, or disorientation; (6) subject requested to stop; or (7) 120 min.

<u>Statistical Analysis</u>:

Gender differences in the dependent variables of $\bar{T}_{sk}$, T_{re}, HR, and SR were determined using a Mann-Whitney U test. $\bar{T}_{sk}$, T_{re}, and HR increased, from the first rest period to the last exercise period. A second Mann-Whitney U test was done to determine the effect of gender on the change in these variables.

Traditional hypothesis testing may not assign significance to large differences between the means when sample size is relatively small. Therefore, effect sizes (ES), the ratios of the differences between population means to the pooled standard deviations, were reported in the results section. ES and the power of traditional hypothesis testing (i.e., t-test) were estimated using software copyrighted by Borenstein and Cohen ([1988] Lawrence Erlbaum Associates, Inc.; Hillsdale, NJ).

B.   RESULTS

<u>Tolerance Time</u>:

The volunteers were able to complete the 120-min tests in all of the cooling conditions. However, in the NC condition, some tests were terminated on the basis of high HR. One woman's test was terminated after 75 min, and two men's tests were terminated at minute 80 and minute 90.

<u>Body Temperatures</u>:

Core temperature recorded in the final minutes of the heat exposure (final T_{re}) tended to be higher in the women than the men (see Figure 1). Final T_{re} differed significantly (p = .006) between women and men only when air cooling was applied (38.3 ± 0.6°C vs. 37.5 ± 0.5°C). In all other conditions, the gender difference in final T_{re} was not statistically significant: NC (38.5 ± 0.7°C vs. 38.3 ± 0.8°C), IVC (38.1 ± 0.4°C vs. 37.7 ± 0.6°C) or WC (37.6 ± 0.2°C vs. 37.5 ± 0.2°C) conditions. Analysis of the increase in T_{re} over time, from the first rest period to the last exercise period in the heat test, revealed no gender difference among conditions.

Final $\bar{T}_{sk}$ did not differ significantly between women and men in the AC (35.2 ± 1.5°C vs. 35.8 ± 0.7°C), NC (37.3 ± 0.3°C vs. 37.0 ± 0.9°C), or WC (31.8 ± 1.0°C vs. 32.0 ± 1.1°C) conditions; however, a gender difference was seen in the IVC condition. In the IVC condition, final $\bar{T}_{sk}$ was significantly higher (p = .02) for the women (37.0 ± 0.6°C) than for the men (36.1 ± 0.7°C). Final $\bar{T}_{sk}$ in the four conditions is shown in Figure 2. Analysis of the increase in T_{re}, from the first rest period to the last exercise period in the heat test, revealed no gender difference among the conditions.

Heart Rate:

Heart rate during the final minutes of the test differed significantly between women and men with AC (142 ± 20 bpm vs. 113 ± 17 bpm [p > .02]), IVC (151 ± 17 bpm vs. 121 ± 21 bpm [p = .02]), and WC (125 ± 10 bpm vs. 104 ± 12 bpm [p = .03]). Final HR was higher in

women than in men when NC was provided, but this difference was not statistically significant (169 ± 7 bpm vs. 142 ± 26 bpm [p = .08]). Final HRs for the four conditions are shown in Figure 3. HR increase, from the first exercise period to the last exercise period during the heat test, revealed a significant gender difference (p = .02) in the WC condition only.

Sweat Rate:

Whole-body SR (L/hr * m^2) did not differ significantly between women and men in any of the conditions: AC (0.29 ± 0.2 vs. 0.34 ± 0.06), NC (0.47 ± 0.05 vs. 0.55 ± 0.15), IVC (0.32 ± 0.14 vs. 0.37 ± 0.08), or WC (0.19 ± 0.5 vs. 0.19 ± 0.08). SR in the four conditions is shown in Figure 4.

Effect Size:

Due to the relatively small sample size, power to detect a significant gender difference using hypothesis testing was low (range of 0.02 to 0.83). With traditional hypothesis testing, large gender differences between means may be overlooked. Hence, ESs for gender difference are provided in Table 2. Cohen in 1988 (15) proposed that an ES of .2 represents small differences, that an ES of .5 represents moderate differences, and that an ES greater than 0.8 represents large differences.

Table 2a -- ES for Gender Difference and Power (AC condition)

Variable	Effect Size for Gender	Power	2-Tailed P level
Final HR	1.53	0.68	0.02*
Change in HR	0.50	0.12	0.36
Final T_{re}	1.59	0.72	0.006*
Change in T_{re}	0.49	0.12	0.39
Final $\bar{T}_{sk}$	0.45	0.11	0.65
Change in $\bar{T}_{sk}$	0.90	0.16	0.43
SR	1.12	0.34	0.13

(* indicates significant gender difference at the p < .05 level)

Table 2b -- ES for Gender Difference and Power (NC condition)

Variable	Effect Size for Gender	Power	2-Tailed P level
Final HR	1.46	0.51	0.08
Change in HR	1.01	0.28	0.31
Final T_{re}	0.78	0.23	0.16
Change in T_{re}	0.70	0.15	0.27
Final $\bar{T}_{sk}$	0.47	0.02	0.60
Change in $\bar{T}_{sk}$	0.32	0.05	0.77
SR	0.72	0.17	0.20

(* indicates significant gender difference at the p < .05 level)

Table 2c -- ES for Gender Difference and Power (IVC condition)

Variable	Effect Size for Gender	Power	2-Tailed P level
Final HR	1.57	0.70	0.02*
Change in HR	0.71	0.20	0.20
Final T_{re}	0.82	0.25	0.11
Change in T_{re}	0.44	0.10	0.63
Final $\bar{T}_{sk}$	1.22	0.47	0.02*
Change in $\bar{T}_{sk}$	0.39	0.09	0.50
SR	0.44	0.10	0.90

(* indicates significant gender difference at the p < .05 level)

Table 2d -- ES for Gender Difference and Power (WC condition)

Variable	Effect Size for Gender	Power	2-Tailed P level
Final HR	1.86	0.83	0.03*
Change in HR	1.88	0.83	0.02*
Final T_{re}	0.66	0.18	0.33
Change in T_{re}	1.20	0.46	0.06
Final $\bar{T}_{sk}$	0.27	0.06	0.82
Change in $\bar{T}_{sk}$	0.11	0.04	0.73
SR			1.00

(* indicates significant gender difference at the p < .05 level)

13

C.   DISCUSSION

1.   No Cooling

During physical work in a high heat-environment, demands for
oxygen delivery and thermoregulation must be met by the cardiovascular
system. To facilitate heat dissipation skin blood flow (SkBF)
increases, which leads to pooling of blood in cutaneous vascular beds.
Pooling causes a reduction in central blood volume (CBV). As CBV
declines, stroke volume (SV) falls and, a compensatory increase in
heart rate ensues. The problem of decreased SV due to elevation in
SkBF is exacerbated by losses in plasma volume due to sweating. It is
the failure of the cardiovascular system to meet both metabolic needs
of working muscles and heat dissipation requirements for thermo-
regulation that causes T_{re} to rise rapidly, SV to fall precipitately,
and/or HR to approach maximal values.

The compensatory increase in HR, in response to an increase in
SkBF, is expected to show a gender difference in magnitude because
women have a smaller blood volume than men. Hence, blood sent to the
periphery to meet cooling needs represents a higher percentage of
total blood volume for women than men. In addition, plasma volume
lost due to sweating represents a greater percentage of total blood
volume for women than for men. Hence, CBV is expected to fall more
rapidly in women than in men when work is required in a hot
environment.

In the NC condition, HR progressively increased, for women and

men, as blood was shunted to the periphery for cooling and body fluids were lost due to sweating. In three individuals (one woman and two men), capability of the cardiovascular system was insufficient to meet both the cooling and metabolic needs of the body. For these three subjects, the test was terminated early because heart rate had reached 90% of the measured HR_{max}. Figure 4 reveals a gender difference HR during the NC test. A gender difference in HR has been shown by others when exercise is required in a hot environment (9-11,16).

Body fluid loss due to sweating contributed to the cardiac drift seen during the NC tests. SR was greater in men (1.9 ± 0.6 L/min) than in women (1.5 ± 0.2 L/min). However, women experienced a 3% greater loss in plasma volume than men did. In the closed environment of chemical protective (CP) garments, sweating is not a particularly effective thermoregulatory response because sweat can not be readily evaporated, and leads to cardiovascular compromise because plasma volume is lost.

The body also rids heat via conduction, convection, and radiation. Transfer of body heat from the core to the periphery is facilitated by cutaneous vasodilation in two ways: (1) heat flows from deep tissues to the circulatory system and the warmed blood is distributed to the skin (i.e., enhancing convective heat transfer), and (2) the warmed blood elevates T_{sk} and increases the temperature gradient between the core and the periphery (i.e., enhancing conductive heat transfer). Transfer of body heat from the body to the environment is also facilitated by vasodilation. The increase in Tsk optimizes heat transfer between the body and the environment. In an

environment where ambient temperature (T_a) is less than Tsk, heat loss to the environment is maximized. Alternatively, when T_a is greater than Tsk, heat gain from the environment is minimized.

In the NC condition, final $\bar{T}_{sk}$ tended to be higher for the women than for the men, but this difference was not statistically significant. This finding is supported by others (16,17). As can be seen in Figure 6, $\bar{T}_{sk}$ increased over time for both the women and men. Although $\bar{T}_{sk}$ was higher than T_a, it cannot be assumed that heat was transferred to the environment, because heat transfer between the body and the environment was affected by the clothing ensemble. In this study, subjects wore multiple layers of clothing: layer 1-shorts, socks, and athletic shoes; layer 2-cotton coveralls; and layer 3-CP ensemble, including bibbed trousers and hooded jacket. The insulation of the clothing ensemble is determined by characteristics of its components. Although thermal resistance of the clothing ensemble was not measured, the CP garment is highly insulative with a clo value of 1.97 (18). Due to high thermal resistance of the CP garment, heat transfer from inside the ensemble to the environment was restricted. Therefore, air temperature in the microenvironment under the CP ensemble could be greater than the T_a. Hence, both the low-moisture permeability and the high-insulating properties of CP clothing prevented heat loss through normal avenues, and heat generated metabolically could not be readily dissipated. Therefore, as can be seen in Figure 7, core temperature increased over time for both sexes. Body temperature tended to be higher in women than in men, but T_{re} increased at a slightly faster rate in men compared with women.

2. Air Cooling

Air cooling has been shown to effectively increase stay time and reduce thermal strain in subjects who are required to perform work in hot environments while encapsulated in CP clothing (19-21). This particular cooling system facilitates convective and evaporative cooling by increasing air flow over the skin. Since air-based MCC functions by increasing evaporative heat loss, the efficacy of this device is dependent on sweat rate capacity.

SR has been shown to be lower in women than in men when at rest in heat (22,23), during exercise in heat (17,24-26), and in response to pilocarpine iontophoresis (27). Since a greater SR confers a larger capacity for heat loss via evaporation, it was uncertain if sweat rate in females would be sufficient to effectively employ air cooling. In addition, it was a concern that cardiovascular compromise, potentiated by plasma volume loss, would be hastened in women when compared with men with air-based MCC.

In this study, an air-based MCS, utilized under a CP ensemble, minimized heat strain in both women and men required to perform moderate work in a hot environment. Although T_{re} was higher in women than in men, T_{re} did not rise appreciably after the first bout of exercise in either sex (see Figure 8). Therefore, enhancing evaporative and convective cooling via an air-based MCS proved to be an effective countermeasure to heat stress in women as well as in men.

The air-based system was effective even though evaporative sweat

rate was lower in the females than in the males (0.16 ± 0.02 vs. 0.21 ± 0.08 L/hr*m^2, respectively). Women tended to lose less body fluid due to sweating than the men did (1.07 ± 0.06 vs. 1.23 ± 0.23 L/hr, respectively). Because women have less blood volume than men, an equivalent loss in body fluid represented a larger portion of women's total blood volume. Hence, in this study, although the women lost less body fluid than the men, the women experienced an 8% greater loss in plasma volume than men experienced. The greater loss in plasma volume may have potentiated a higher HR response in women compared with men. Heart rate tended to be higher in women than in men across all time points, and a statistical difference was seen in the final value for HR (see Figure 9). Caution is warranted for application of this cooling device for women and men when drinking water is limited, or when the design of the protective gear renders drinking difficult. Caution is also warranted for women when this device is used in situations requiring higher SRs, over longer durations, or at higher work loads.

   3.   Ice Vest Cooling

Currently, when physical work is required aboard ships in hot environments, a cooling system is utilized that consists of a vest that holds frozen gel packs against the torso. Use of this vest has been shown to extend stay time and decrease thermal strain in men required to perform work in a hot environment (28,29). However, it was uncertain if the vest would be equally effective in minimizing heat strain for women.

The ice vest provides conductive cooling over the torso region of the body. To enhance heat exchange between the body and the vest, body surface area in contact with the vest must be maximized. In women contact is limited by two anthropometric characteristics: (1) women have less torso surface area than men, and (2) women have body curves in both the two- and three-dimensional plane. In this study, the women indicated that the gel packs tended to be in contact with their body across the top of the chest and shoulders, and across the buttocks, but were not in contact with their body in the midthoracic region. Thus, IVC may be less effective in women because less body surface area is in contact with the gel packs. Results from this condition show that women had both a higher T_{re} and a higher $\bar{T}_{sk}$ than men did (see Figures 10 and 11). These results indicate that the vest provided better cooling to men than to women.

The vest comes in only one size and has a mass of 5 kg; thus, use of this MCC device required the women to work at a greater percentage of their maximal capacity, and to perform work at a higher percentage of HR_{max} than the men. Over time HR was higher in the women than in the men (see Figure 12); a statistically significant gender difference was revealed for final HR.

The gender difference in HR response during the IVC condition may be due to a number of factors. As indicated by higher T_{sk}, peripheral blood flow may be higher in women than in men. It is possible that by distributing more blood flow to the periphery, effective CBV fell, and HR increased to maintain cardiac output. In addition, women lost 3% more plasma volume than the men did, even though women lost less body

fluid (1.17 ± 0.25 L/min) than the men did (1.35 ± 0.34 L/min). Thus, heart rate may have been higher in the women than in the men because of the following: (1) women were required to work at a higher percentage of their maximal capacity, and (2) effective CBV was lower due to increased peripheral blood flow and greater plasma volume loss when compared with men.

4.   Water Cooling

Water-based MCC has been explored as a means of negating thermally hostile environments. Water-based MCSs have been shown to minimize heat strain at light-to-moderate exercise intensities (28,30,31). Because women have a greater surface-to-mass ratio (4-6) and a greater $\bar{T}_{sk}$ than men do (9), we felt that a water-based cooling system may be the most effective type of system for women.

Although T_{re} over time was higher in the women than in the men (see Figure 13), the rise in body temperature was greater in the men than in the women. $\bar{T}_{sk}$ over time was lower in women than in men (see Figure 14). This water-based MCS provided sufficient cooling such that SR was minimized in both sexes. HR across time was significantly higher in the women than in the men (see Figure 15). This HR gender difference likely was due to a gender difference in cardiovascular capability, since the MCS added 8 kg of mass, rather than due to a gender difference in MCC efficacy, since the T_{re} rise was greater in the men than in the women.

VII. CONCLUSION

In this study we tested the efficacy of three MCSs by comparing indices of heat strain (e.g., HR, T_{re}, $\bar{T}_{sk}$, and SR). Preliminary examination of the data indicate the following findings:

* Each of the MCSs reduced indices of heat strain in women and men when compared to the NC condition;

* The men experienced equivalent reductions in HR and T_{re} with all three types of MCC when compared to the NC condition;

* For women, WC was clearly more effective than either AC or IVC;

* For women, the reduction in T_{re} and $\bar{T}_{sk}$ realized with WC, when compared to NC, was greater than the reduction in T_{re} and $\bar{T}_{sk}$ realized by the men with WC, when compared to NC; ·

* Use of MCS presented problems for the women:

> * The weight of the WC and IVC was especially burdensome;

> * Efficacy of the IVC may have been effected by body surface area in contact with the cooling packs.

Based on these preliminary findings we have the following recommendations:

* Reengineer the vest to enable the packs to conform better to the female physique;

* Reduce the weight of the MCSs;

* Avoid AC use by women in situations requiring high SRs, long durations, high work loads, or when drinking water is limited.

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Figure 1 -- Final Core Temperature in Women and Men
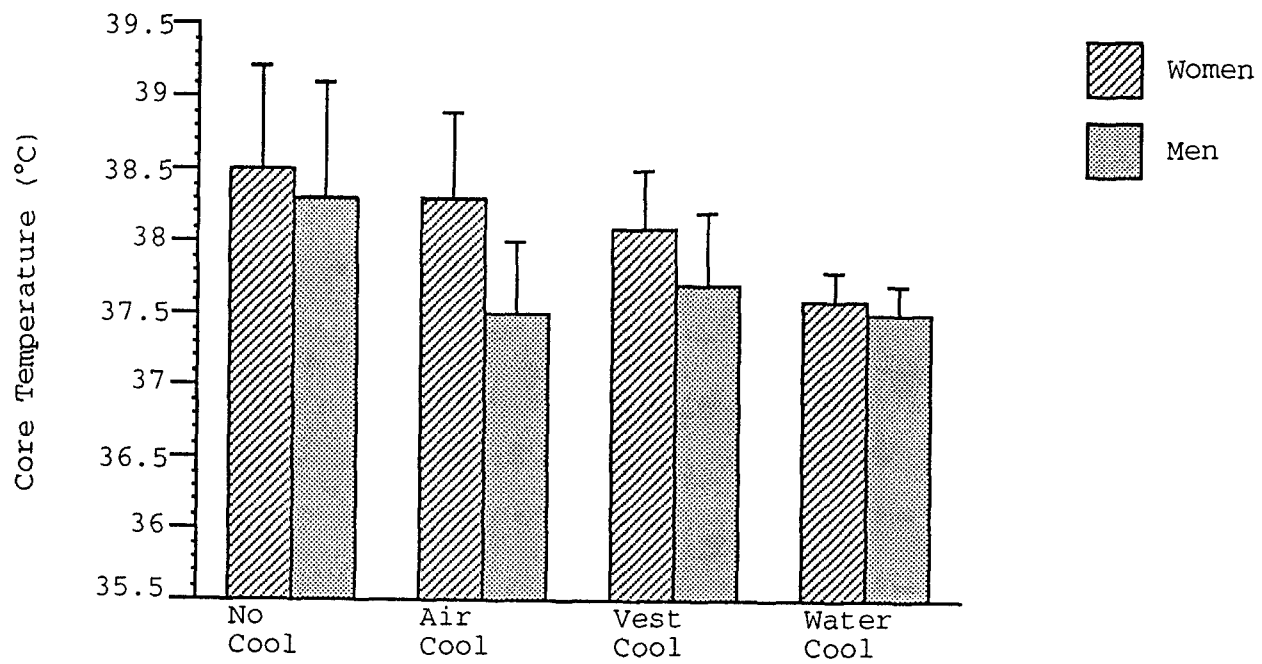
Figure 2 -- Final Skin Temperature in Women and Men
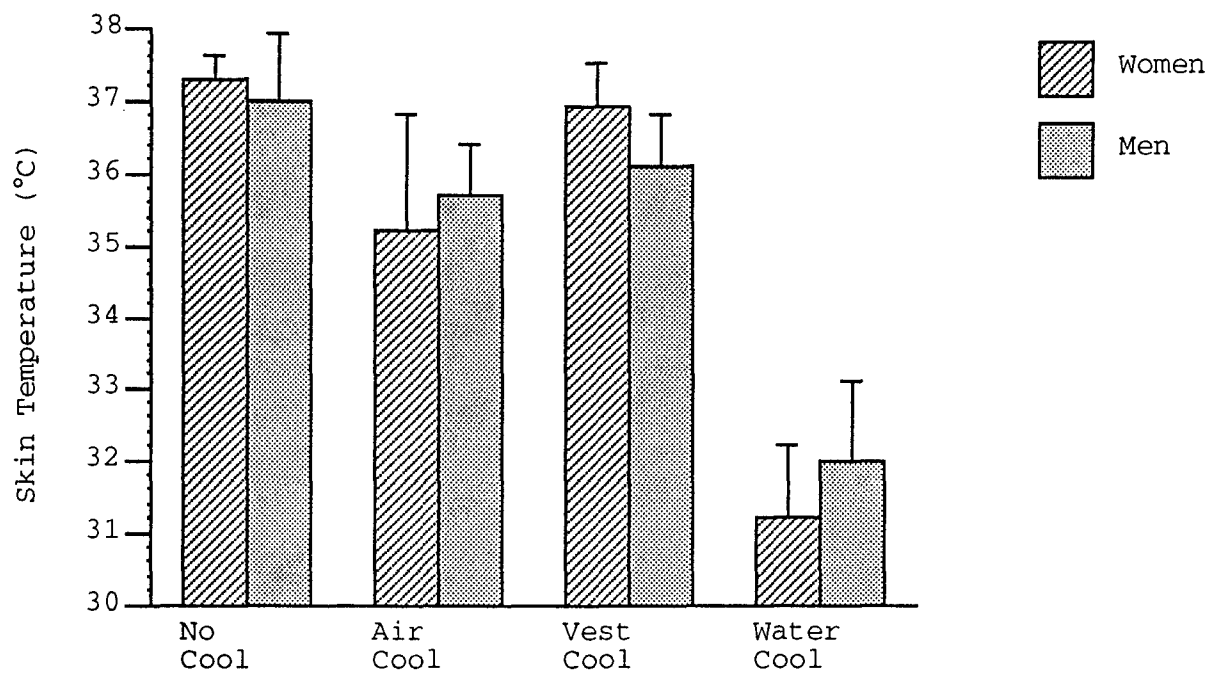
Figure 3 -- Final Heart Rate in Women and Men
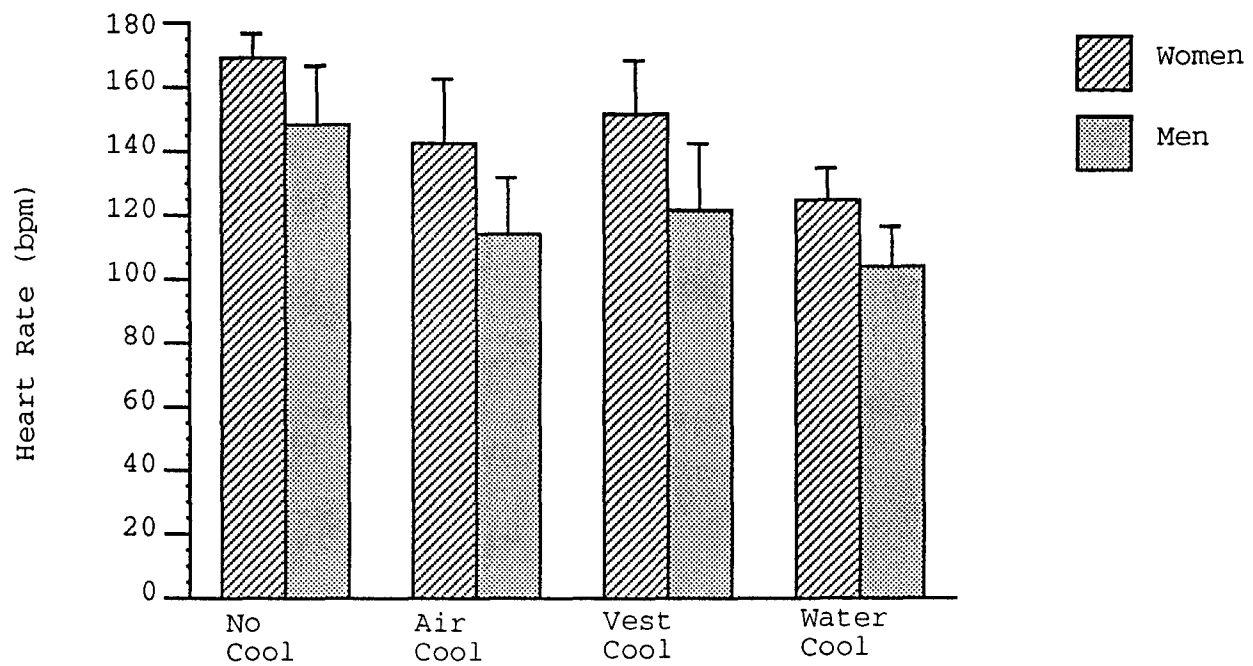
Figure 4 -- Final Sweat Rate in Women and Men
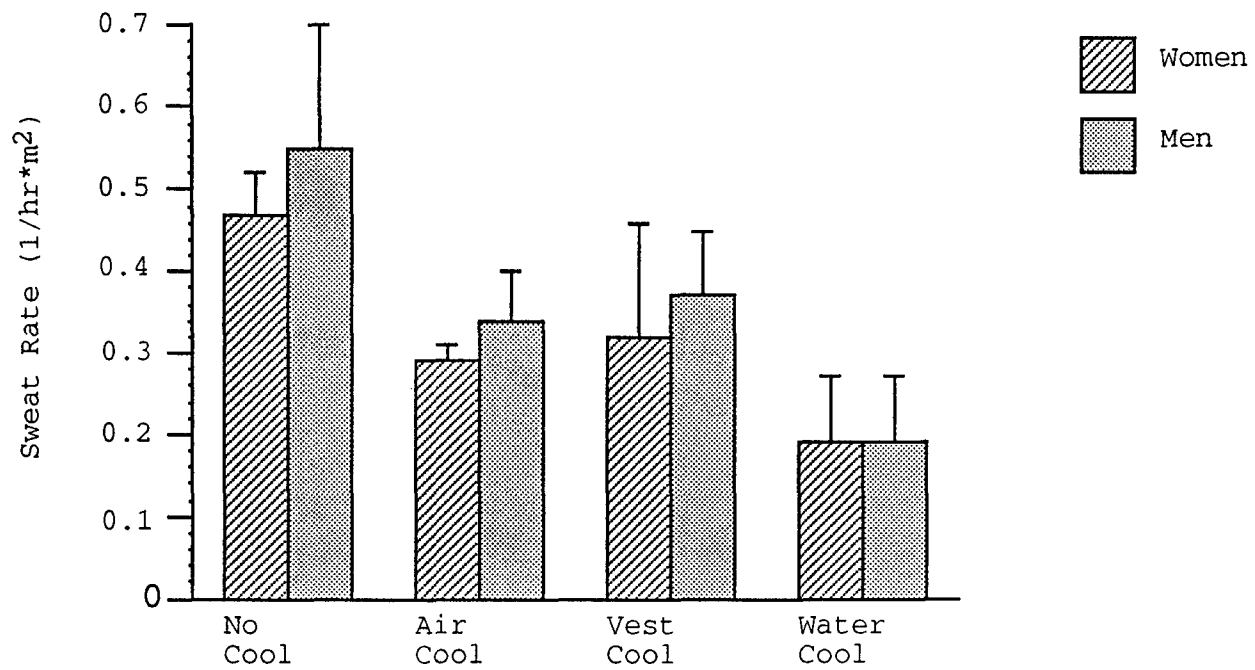
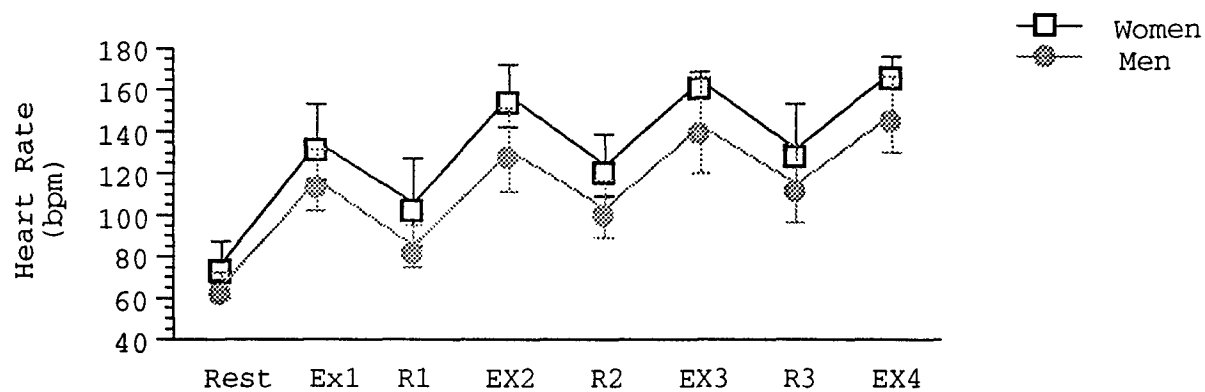Figure 5 -- Heart Rate Over Time in Women versus Men
No Cooling

Figure 6 -- Mean Skin Temperature Over Time in Women Versus Men
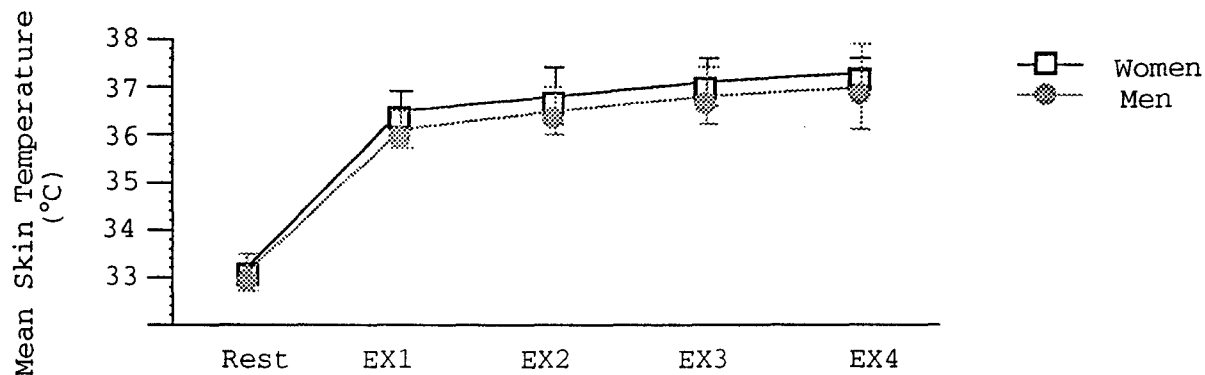No Cooling

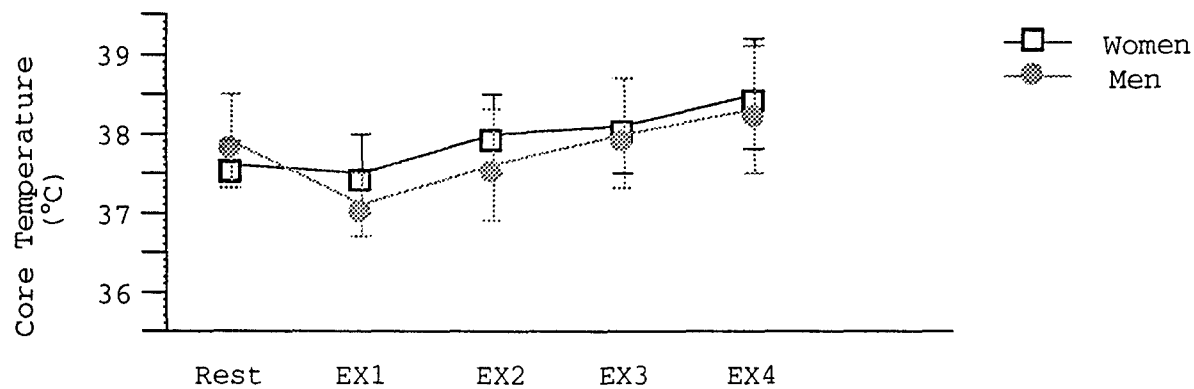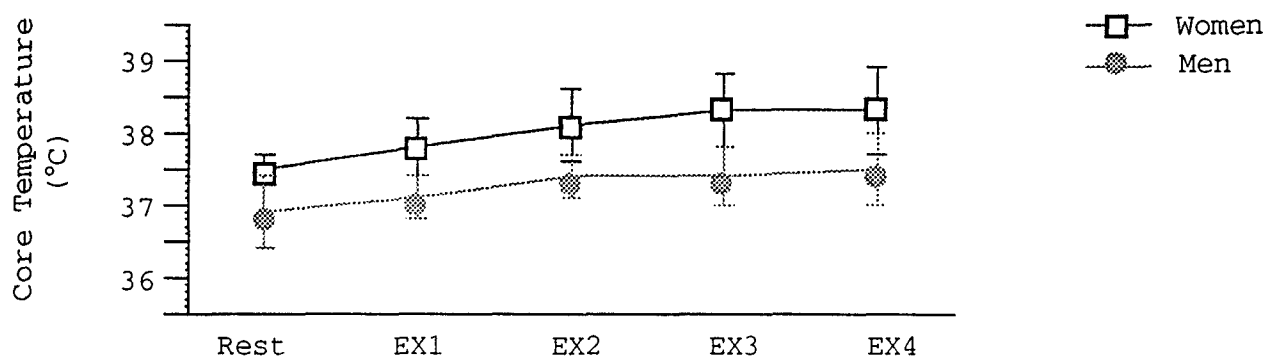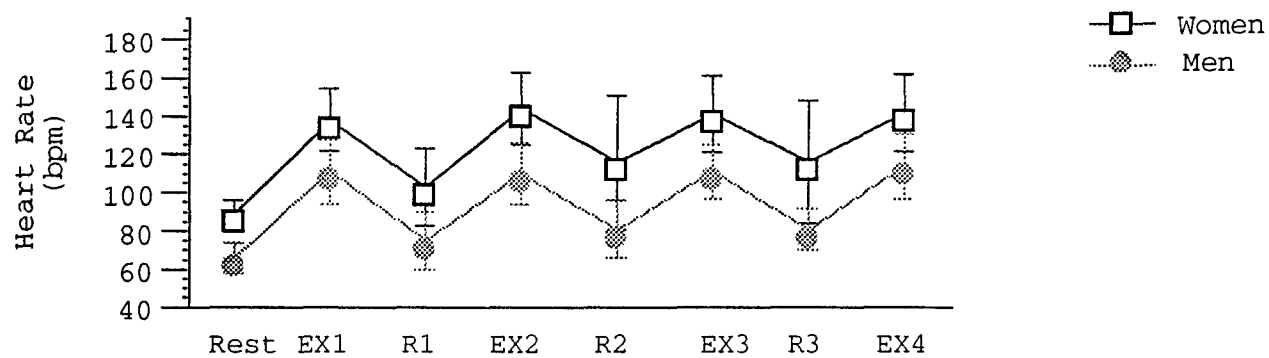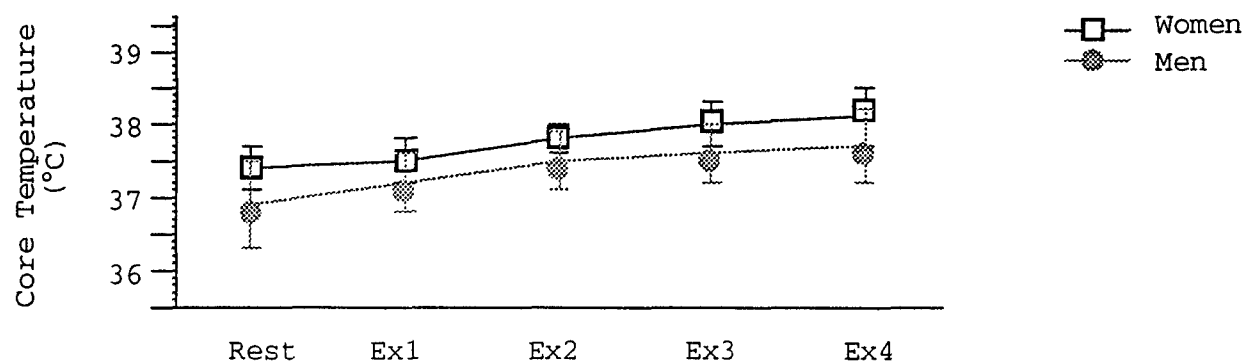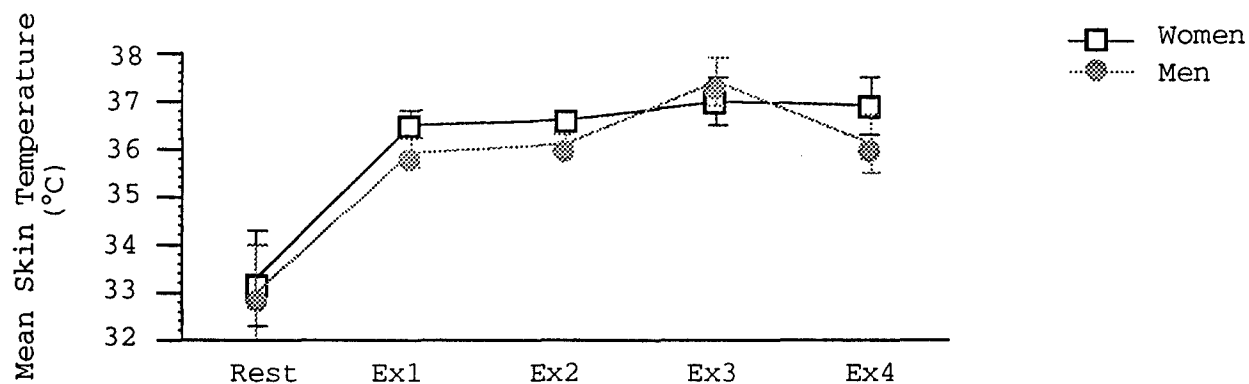Figure 7 -- Core Temperature Over Time in Women Versus Men
No Cooling

Figure 8 -- Core Temperature Over Time in Women Versus Men
Air Cooling

Figure 9 -- Heart Rate Over Time in Women Versus Men
Air Cooling

Figure 10 -- Core Temperature Over Time in Women Versus Men
Vest Cooling

Figure 11 -- Mean Skin Temperature Over Time in Women Versus Men
Vest Cooling

Figure 12 -- Heart Rate Over Time in Women Versus Men
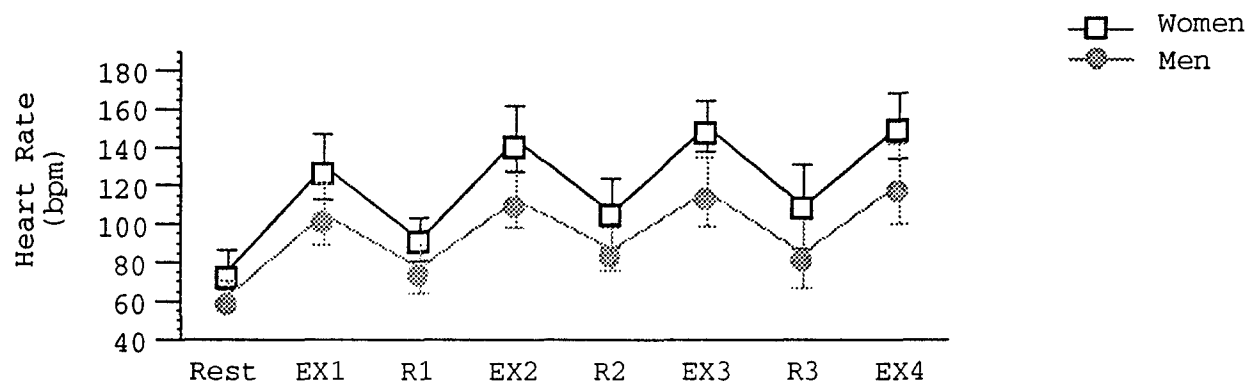## Vest Cooling

Figure 13 -- Core Temperature over Time in Wome Versus Men
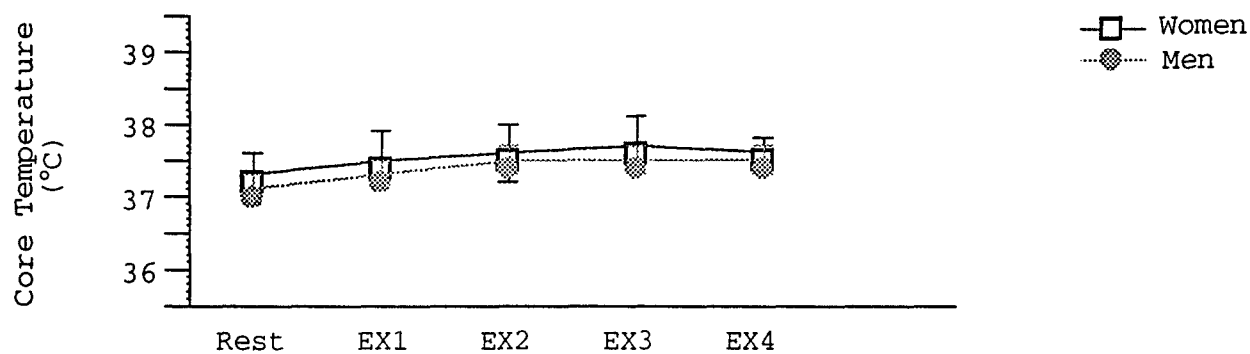Water Cooling

Figure 14 -- Mean Skin Temperature Over Time in Women Versus Men
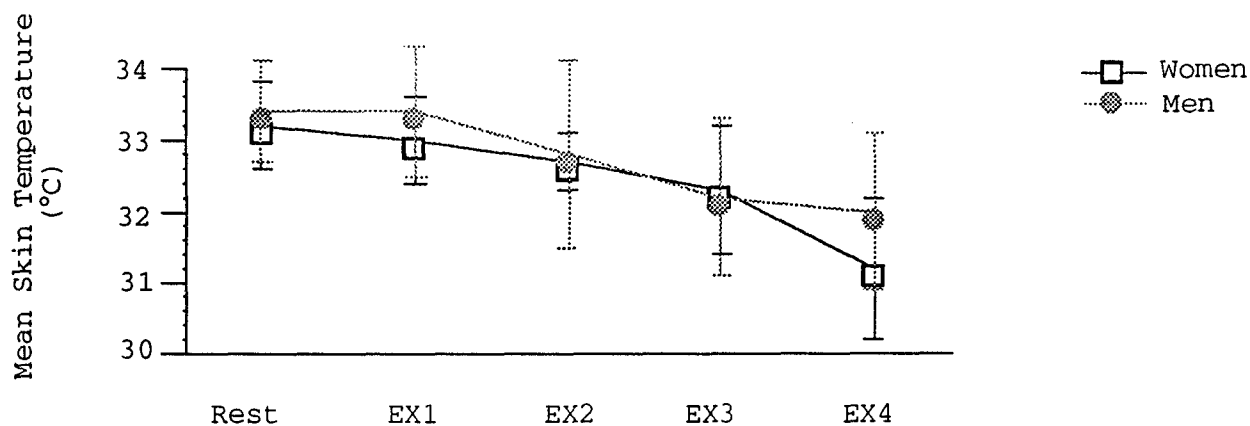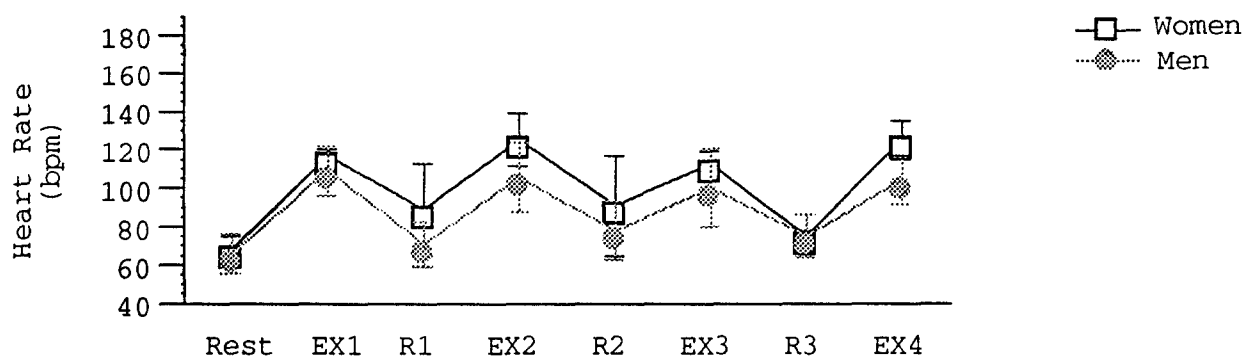Water Cooling

Figure 15 -- Heart Rate over Time in Women Versus Men
Water Cooling

REPLY TO
ATTENTION OF:

MCMR-RMI-S   (70-1y)   9 Mar 98

MEMORANDUM FOR Administrator, Defense Technical Information
            Center, ATTN: DTIC-OCP, Fort Belvoir,
            VA   22060-6218

SUBJECT: Request Change in Distribution Statement

1. The U.S. Army Medical Research and Materiel Command has
reexamined the need for the limitation assigned to technical
reports written for the following contracts. Request the
limited distribution statement for these contracts be changed
to "Approved for public release; distribution unlimited." These
reports should be released to the National Technical Information
Service.

Contract Number	Accession Document Number
DAMD17-94-J-4407	ADB224557
DAMD17-95-1-5048	ADB230013
DAMD17-95-C-5006	ADB219041
95MM5508	ADB227588
95MM5522	ADB229897
95MM5537	ADB227721
95MM5596	ADB229924
96MM6652	ADB220033
96MM6653	ADB221466
96MM6654	ADB222409

2. Point of contact for this request is Ms. Betty Nelson at
DSN 343-7328 or email: betty_nelson@ftdetrck-ccmail.army.mil.

FOR THE COMMANDER:

PHYLIS M. RINEHART
Deputy Chief of Staff for
    Information Management

completed
2-5-2000
Bw